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CHAPTER 3

USE OF TASK TIMELINE ANALYSIS TO ASSESS CREW WORKLOAD

by

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INTRODUCTION

As systems have become more sophisticated, the role of humans in operating and maintaining them has grown more complex. There has been a steadily growing recognition that human characteristics, particularly limitations and abilities, must be considered in some depth in system design if design objectives are to be met.

The size and role of the crew represent critical design decisions. Mission performance has a direct relationship to the ability of the crew to carry out all of the required functions. If necessary functions overload the crew, some will be omitted and others ineffectively performed. If this is the case, automation may have to be considered. If the crew is underloaded, boredom and reduced performance may result, in addition to unnecessary costs being incurred. An additional crew member will increase weight, design costs, fuel expenditures, and training costs. It has been estimated that, for a commercial aircraft, an additional flight crew member can result in a 4 to 5 percent increase in direct operating costs. In the same manner, for a military aircraft fleet of 200 with a life-cycle of 20 years, costs can amount to several hundred million dollars for each additional crew member.

Issues of crew size were so critical in preliminary design work for proposals on antisubmarine warfare (ASW) and airborne warning and control system aircraft (AWACS) that Douglas Aircraft Company conducted research on the problem. The use of workload measures to assess the viability of a selected crew complement as well as other crew interfaces was considered. It was established that a workload assessment method should be capable of being applied early in the design phase, be expressed in quantitative terms, be understandable, and be relevant to the needs of the engineer. It must also have reasonable validity, be repeatable, be low cost, and need only a short turnaround time to produce results. Finally, the method must include consideration of the following: mission requirements and parameters, aircraft performance, equipment design, operational procedures, environmental factors, and crew station configuration.

The subject of workload has received extensive treatment in the literature (1 to 4) and is still being pursued in research and development efforts. Work is currently in progress throughout the industry on a number of varied approaches, including the following:

Subjective assessments employing rating scales.

Physiological measures, including heart rate variables, muscle activity or "arousal" indices, and more recently, electroencephalographic data such as the event-related potential

Performance and/or behavioral measures

Task/timeline analysis measures.

Of the items listed above, the task/timeline approach appeared to be the most easily implemented and could meet most of the established criteria. A model was developed by Douglas Aircraft Company to utilize this workload measure in the design, verification of design improvements, and certification of recent aircraft. This approach will be presented in this paper.

Task analysis may be defined as the systematic determination of the activities required of personnel in the performance of a function or set of functions. Workload analysis, which employs a task analysis base, provides an appraisal of crew task loading resulting from the sequential accumulation of task times. This permits an evaluation of the capability of the crew to perform all assigned tasks in the time allotted by mission constraints.

This analytic approach is derived from methods developed early in this century called "time and motion studies" which were aimed at making industrial workers more efficient in the performance of manual tasks. Task analysis was promoted as a useful tool in system design starting in the early 1950s.

In general, applications identified for task analysis include crew duty allocation and the assessment of design alternatives, personnel and training requirements, human reliability and safety, maintainability and workload. They are also used in the development of operational procedures. Several specific approaches have been developed (5).

In spite of certain limitations, the task/timeline methods seemed to offer promise for meeting many of our criteria such as quantitativeness, availability early in design and responsiveness to mission and operational parameters. It was equipment-oriented and met the needs of our designers. If applied consistently, it should be reliable.

Because there is no universally acceptable scale of workload, the data are normally used comparatively; that is, if a baseline workload were developed for an aircraft, or subsystems, or both, this could be used to determine if the system under consideration resulted in a greater, equal or less task workload than the baseline. In addition several configurations could be compared to determine which has the lowest workload and the percentage differences.

The task/timeline workload assessment methodology, when first applied in 1975, proved to be rather labor-intensive. It, however, showed promise of being suitable for computerization of many of the activities, ultimately resulting in reduced cost

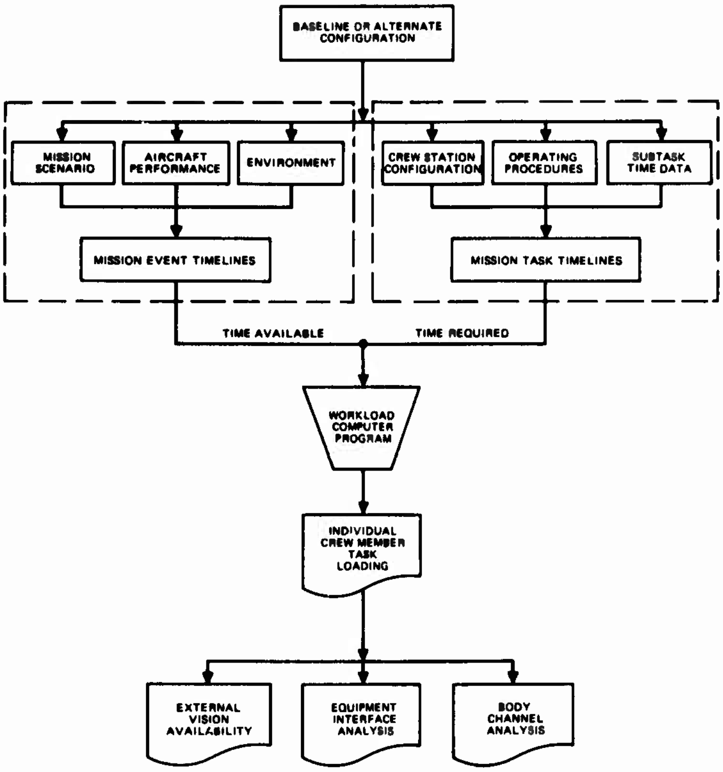


FIGURE 1. CREW STATION WORKLOAD ANALYSIS AND DESIGN SYSTEM (CWADS)

and time during the analysis process. Consequently, the task/timeline analysis approach was developed and partially applied to the DC-9-50 design. It has been used extensively in later design activities and is currently being used in flight deck and work station configuration development for Douglas Aircraft. It was applied to verify workload improvements for the MD-80 series and to demonstrate compliance with Federal Aviation regulations. For future aircraft now in design, it is employed in trade studies and for early design assurance that tasks during critical mission phases; including contingencies, can be performed by the available crew.

METHODOLOGY

Figure 1 shows the several analytic steps used in the basic approach to workload studies. Initially, mission analysis is employed to determine and size the parameters of the total functional system in which the crew and equipment will operate. The analysis is also used to organize the mission into phases and segments bounded by milestones to assist in system definition and establish top-level functions. This analysis is the foundation of an iterative descending hierarchy which, by further functional analysis and task analysis, ultimately reaches the irreducible task/subtask level (6).

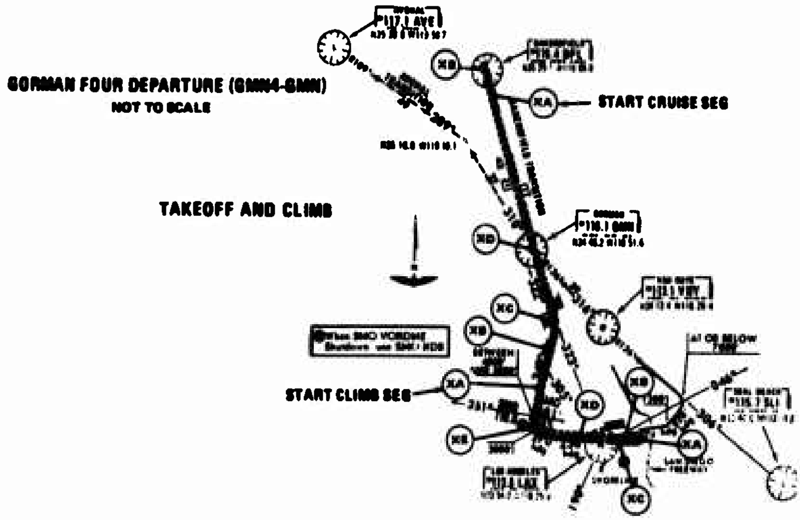
The task analysis represents a detailed baseline that is effectively used to establish a comprehensive crew/equipment data store. At this level, comprehensive information on the tasks and task elements is developed from the previous mission and function analyses. The files of baseline data serve as the working library for preparation of crew workload reports.

WORKLOAD DEFINITION

Crew workload is defined as the ratio of time required by the crew to perform work tasks to the time available within a given mission, phase, or segment.

A workload index (WI) is computed which is expressed as the ratio of the total task performance time to the time available within the constraints imposed by mission requirements and aircraft flight parameters. The basic formula for computing the index is:

$W_I = (T_R/T_A) \times 100$
where T_R = time required
T_A = time available



		TAKEOFF	STRT TM H M S	DURTN MIN
0203	XA	READY FOR TAKEOFF	00:00:00	0.17
0203	XB	RELEASE BRAKES, ACCELERATE TO VR	00:00:10	0.42
0203	XC	ATTAIN VR, ROTATE, CLIMB TO 1,000 FEET	00:00:35	0.52
0203	XD	ATTAIN 1,000 FEET, CLIMB TO 3,000 FEET	00:01:06	1.18
0203	XE	ATTAIN 3,000 FEET, FLY TO SMO 261 RADIAL	00:02:17	2.43
		AVERAGE		4.72
0204	XA	ESTABLISH CLIMB TO CRUISE ALTITUDE	00:04:43	2.65
0204	XB	CHANGE AIRSPEED AT 10,000 FEET	00:07:22	1.77
0204	XC	GORMAN VOR 322 RADIAL TRANSITION	00:09:08	4.47
0204	XD	ARRIVE GORMAN VOR	00:13:36	6.28
0204	XE	ARRIVE BAKERSFIELD VOR	00:19:53	1.90
		AVERAGE		17.07

FIGURE 2. TAKEOFF AND CLIMB SEQUENCE

INPUTS

Time Available

To provide a framework for the detailed analysis, a scenario is divided into mission phases. Each phase is subdivided into discrete segments, bounded by specific operational milestones that define the start and end times based on aircraft performance characteristics, or mission parameters, or both.

Figure 2 illustrates the takeoff and climb phases at the start of a typical scenario from which time available parameters will be developed. The phases are then subdivided into segments — each bounded by a specific milestone (XA, XB, ..., XZ) denoting start and end times — which are derived from the aircraft performance characteristics and mission profile requirements. These relationships are shown in Figure 3. The difference between segment start and end times is the time available.

Time Required

Developing the time required begins with the use of crew station configuration drawings and proposed operating procedures for the aircraft and its specific equipment. All of the aircrew tasks and subtasks that must be performed between milestones are then detailed in chronological order and entered in the computer task file along with codes identifying specific equipment interfaces. The identity of the particular crew member performing that subtask and the specific body channels utilized (eyes, hands, etc) are also recorded. Working closely with flight personnel experienced in similar aircraft, a very detailed description of the procedures required to accomplish each mission segment is developed (down to a microlevel — eg move hand to switch). A typical sequencing is depicted in Figure 4.

As the detailed subtask and equipment listings are completed, individual "time required" values are assigned for each operator activity. These time estimates are derived from the following sources:

Index of Electronic Equipment Operability, developed by the American Institute for Research (AIR) (7)

A Douglas-developed model defining reach time as a function of distance.

Direct action time measurements recorded during procedural trials in a crew station development mockup.

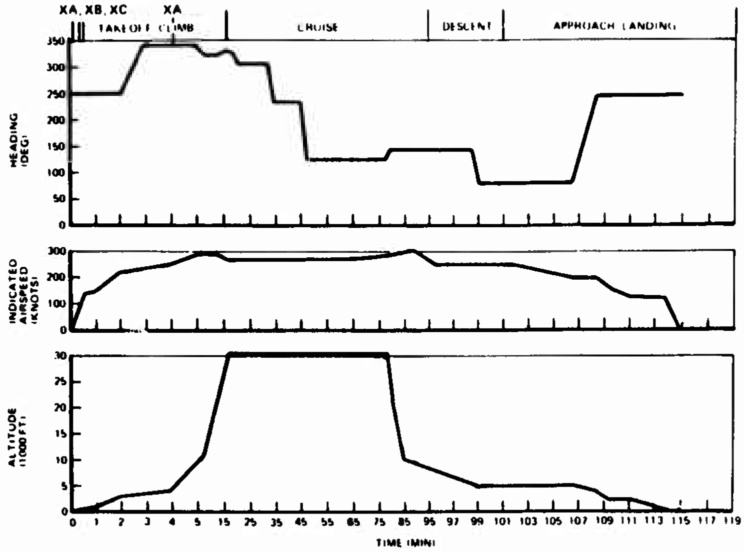


FIGURE 3. FLIGHT PROFILE RELATIONSHIPS – ALTITUDE, AIRSPEED, AND HEADING VERSUS TIME

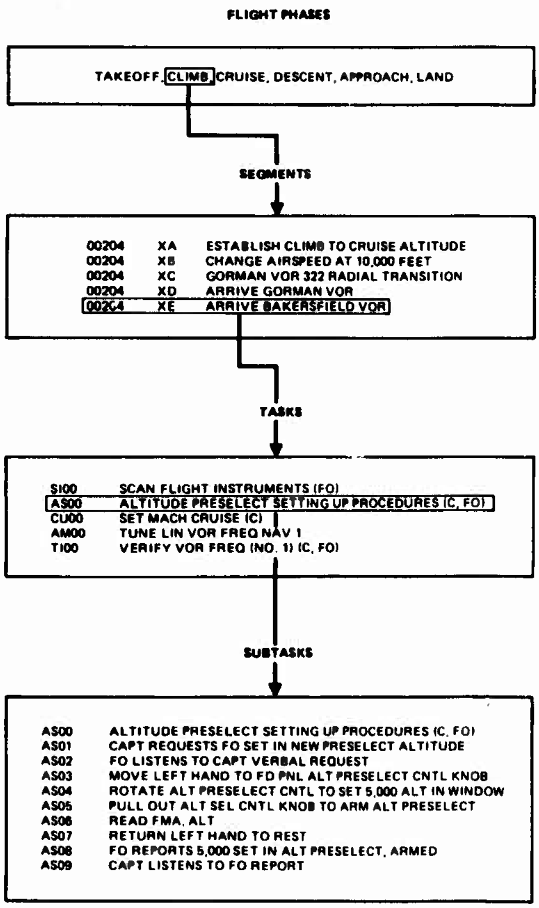


FIGURE 4. SEQUENCING STRUCTURE FOR COMPUTER INPUT

Time-referenced video recordings acquired during previous in-flight micromotion studies conducted by Douglas.

Timing verbal communications by stopwatch.

PROGRAM OUTPUTS

Equipment Interface Workload (Total Workload)

The crew workload produced by interfacing with equipment is defined as the total percentage of time that is utilized by the crew members in completing their assigned tasks while operating the aircraft during the mission. The computer program sums each individual crew member's task times and relates this to the time available in each segment of a particular mission. Since the program treats all subtasks as occurring in a series and does not reflect the human capability for simultaneous task performance such as listening while setting a switch, the workload values computed for an individual crew member can be considered conservative. These measures of workload are combined on a time-weighted basis to provide for an assessment of workload for each flight segment as well as an overall average for the entire flight. The program is capable of presenting both alphanumeric (Table 1) and graphic outputs (Figure 5) for further detailed analysis.

TABLE 1
CREW WORKLOAD INDEX SUMMARY
EQUIPMENT INTERFACE

AIRCRAFT: MD-XX ANALYSIS: TEST , REVISION:
FLIGHT FROM LAX TO LAX

FUNC	NLST	TITLE	STRT TM H M S	DURTN MIN	WORKLOAD INDEX C	FO
0203	XA	READY FOR TAKEOFF	00:00:00	0.17	70.70	62.20
0203	XB	RELEASE BRAKES, ACCELERATE TO VR	00:00:10	0.42	24.00	30.44
0203	XC	ATTAIN VR, ROTATE, CLIMB TO 1000 FEET	00:00:35	0.52	47.74	38.97
0203	XD	ATTAIN 1000 FEET, CLIMB TO 3000 FEET	00:01:06	1.18	39.38	47.60
0203	XE	ATTAIN 3000 FEET, FLY TO SMO 261 RADIAL	00:02:17	2.43	19.95	30.25
		SEGMENT AVERAGE		4.72	30.02	36.72
0204	XA	ESTABLISH CLIMB TO CRUISE ALTITUDE	00:04:43	2.65	8.43	13.26
0204	XB	CHANGE AIRSPEED AT 10,000 FEET	00:07:22	1.77	17.90	44.88
0204	XC	GORMAN VOR 322 RADIAL TRANSITION	00:09:08	4.47	16.60	18.24
0204	XD	ARRIVE GORMAN VOR	00:13:36	6.28	14.83	18.75
0204	XE	ARRIVE BAKERSFIELD VOR	00:19:53	1.90	28.32	42.21
		SEGMENT AVERAGE		17.07	16.12	23.08
0301	XA	CRUISE TO FRESNO VOR	00:21:47	11.33	7.22	4.21
0301	XB	ARRIVE FRESNO VOR	00:33:07	13.22	6.07	5.61
0301	XC	ARRIVE LINDEN VOR	00:46:20	9.00	9.57	8.24
0301	XD	ARRIVE OAKLAND VOR	00:55:20	23.73	5.77	6.71
0301	XE	ARRIVE AVENAL VOR	01:19:04	16.53	47.40	50.31
		SEGMENT AVERAGE		73.82	15.83	16.08
0401	XA	VLR OVER FIM VOR, TURN, DESCEND	01:35:36	4.25	24.66	24.45
0401	XB	ARRIVE SADDLE INTERSECTION	01:39:51	0.57	16.18	8.09
0401	XC	ARRIVE 5000 FEET	01:40:25	2.83	20.96	29.64
		SEGMENT AVERAGE		7.65	22.66	25.16
0403	XA	VER SMO VOR, TURN TO 068 DEGREES	01:43:15	4.67	16.76	20.57
0403	XB	TURN TO 225 DEGREES	01:47:55	1.70	41.31	29.09
0403	XC	INTERCEPT ILAX LOCALIZER	01:49:37	1.20	19.17	16.44
0403	XD	ARRIVE 2200 FEET	01:50:49	1.75	35.07	20.19
0403	XE	ARRIVE OUTER MARKER FLY TO MIDDLE MARKER	01:52:34	2.67	14.71	31.49
		SEGMENT AVERAGE		11.98	22.70	24.91
0404	XA	CONTINUE DESCENT, MIDDLE MARKER TO MAIN GEAR TOUCHDOWN	01:55:14	0.32	24.37	34.68
0404	XB	ROLLOUT FROM TOUCHDOWN TO RUNWAY CLEARANCE	01:55:33	0.80	42.79	19.71
		SEGMENT AVERAGE		1.12	37.57	23.96
		OVERALL AVERAGE		116.35	17.81	19.53

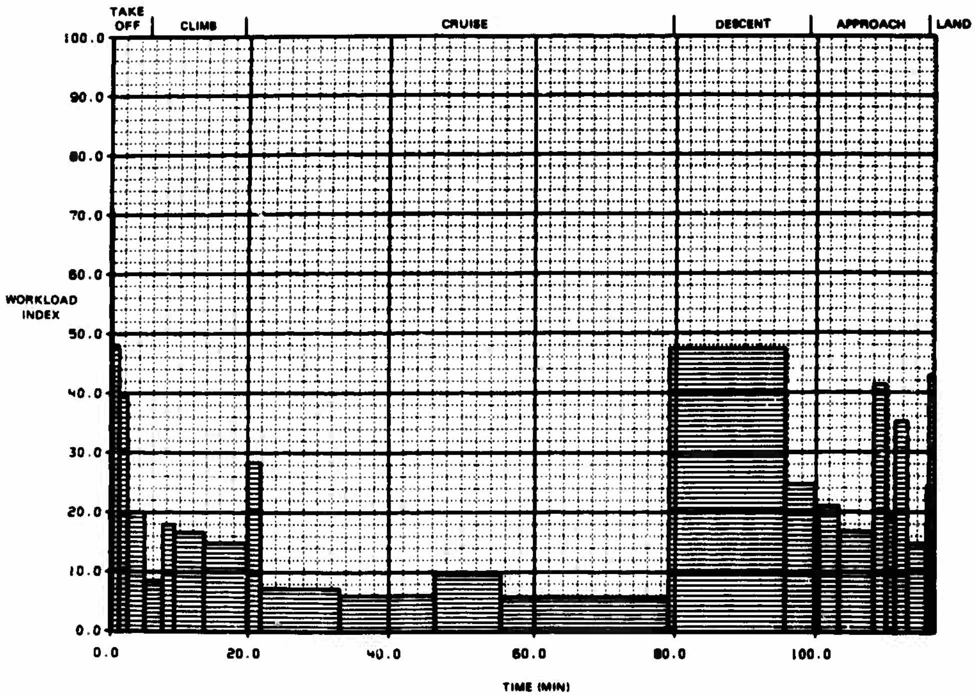


FIGURE 6. EQUIPMENT INTERFACE CREW WORKLOAD – CAPTAIN

Body Channel Workload

The quantification and evaluation of flight crew workload involves consideration of the overt physical actions taken by the flight crew to operate the aircraft. The program then determines the detailed work allocation as a five-channel input/output subsystem on a task-time basis for each crew member. It reflects a composite of the physical actions, reactions and perceptions necessary to fly an aircraft along a prescribed flight path. The flight crew workload analysis thus produces results in tabular and graphic format, reflecting the combined duty cycle of total visual, aural, vocal, and body extremity activity.

All flight crew subtasks are coded in accordance with the following body channel scheme:

V/A — Verbal/aural tasks
IV — Internal visual tasks
L — Left-hand tasks
R — Right-hand tasks
F — Foot tasks

The overall flight deck activities involved in each flight segment are then analyzed in terms of the individual body channel utilization as a ratio of time required to time available. The results enable specific deficiencies to be identified in the functional arrangement of equipment through examination of peak values that might cause crew overload for an individual body channel.

Examples of the alphanumeric and graphic outputs are shown in Table 2 and Figure 6, respectively.

External Vision Availability

Time is required for crew members to view cockpit displays and controls during the course of the flight, and the remaining time can be considered as available for crew members to scan the outside environment. This analysis determines the amount of time available for a crew member to scan the airspace for traffic as well as to keep the runway in view during operations in the terminal area, both of which are important duties from a safety viewpoint.

The computer program examines data in the vision task file, sorts the data, and prints out the external vision time available for crew members as a function of the milestone start times and duration. In addition, for a two-pilot aircraft, a routine is provided to combine the Captain's and First Officer's external viewing time and present the information in graphic form so that total external vision available to both crew members may be ascertained throughout the flight. Typical vision analysis data outputs are shown in Table 3 and Figure 7.

Additional Capabilities

The amount of detailed information coded in the data files of the workload program provides additional analytic capability. The following crew interface relationships can also be evaluated:

TABLE 2
BODY CHANNEL UTILIZATION SUMMARY – CAPTAIN

AIRCRAFT: MD-XX ANALYSIS: TEST , REVISION:
FLIGHT FROM LAX TO LAX

CREW MEMBER = C:CAPTAIN

FUNC	MLST	TITLE	STRT TM H M S	DURTN MIN	BODY CHANNEL INDEX V/A	IV	L	R	F
0203	XA	READY FOR TAKEOFF	00:00:00	0.17	38.0	32.7	0.0	19.7	0.0
0203	XB	RELEASE BRAKES, ACCELERATE TO VR	00:00:10	0.42	9.6	4.0	0.0	2.4	8.0
0203	XC	ATTAIN VR, ROTATE, CLIMB TO 1000 FEET	00:00:35	0.52	15.5	20.5	16.1	21.9	0.0
0203	XD	ATTAIN 1000 FEET, CLIMB TO 3000 FEET	00:01:06	1.18	20.0	17.6	0.0	9.8	0.0
0203	XE	ATTAIN 3000 FEET, FLY TO SMO 261 RADIAL	00:02:17	2.43	6.7	12.0	0.0	6.1	0.0
		AVERAGE		4.72	12.37	14.35	1.77	8.75	0.71
0204	XA	ESTABLISH CLIMB TO CRUISE ALTITUDE	00:04:43	2.65	2.9	5.1	0.0	2.5	0.0
0204	XB	CHANGE AIRSPEED AT 10,000 FEET	00:07:22	1.77	9.7	7.6	0.0	2.8	0.0
0204	XC	GORMAN VOR 322 RADIAL TRANSITION	00:09:08	4.47	9.1	7.2	0.0	2.8	0.0
0204	XD	ARRIVE GORMAN VOR	00:13:36	6.28	4.1	9.9	1.8	6.0	0.0
0204	XE	ARRIVE BAKERSFIELD VOR	00:19:53	1.90	13.9	13.9	0.0	7.4	0.0
		AVERAGE		17.07	6.90	8.67	0.66	4.43	0.0
0301	XA	CRUISE TO FRESNO VOR	00:21:47	11.33	1.5	5.4	0.0	3.2	0.0
0301	XB	ARRIVE FRESNO VOR	00:33:07	13.22	1.3	4.6	0.0	2.6	0.0
0301	XC	ARRIVE LINDEN VOR	00:46:20	9.00	1.9	7.3	0.0	4.3	0.0
0301	XD	ARRIVE OAKLAND VOR	00:55:20	23.73	2.1	3.5	0.0	1.6	0.0
0301	XI	ARRIVE AVENAL VOR	01:19:04	16.53	22.9	23.9	4.5	5.8	0.0
		AVERAGE		73.82	6.50	9.03	1.01	3.31	0.0
0401	XA	VLR OVER FIM VOR, TURN, DESCEND	01:35:36	4.25	9.6	14.8	0.0	8.1	0.0
0401	XB	ARRIVE SADDLE INTERSECTION	01:39:51	0.57	0.0	16.2	0.0	0.0	0.0
0401	XC	ARRIVE 5000 FEET	01:40:25	2.83	14.8	6.1	0.0	0.0	0.0
		AVERAGE		7.65	10.85	11.67	0.0	4.49	0.0
0403	XA	VLR SMO VOR, TURN TO 068 DEGREES	01:43:15	4.67	4.3	12.0	0.0	5.6	0.0
0403	XB	TURN TO 225 DEGREES	01:47:55	1.70	20.4	19.7	0.0	8.9	0.0
0403	XC	INTERCEPT ILAX LOCALIZER	01:49:37	1.20	6.4	11.9	0.0	7.1	0.0
0403	XD	ARRIVE 2200 FEET	01:50:49	1.75	11.7	22.2	0.0	5.5	0.0
0403	XE	ARRIVE OUTER MARKER FLY TO MIDDLE MARKER	01:52:34	2.67	6.6	7.6	0.0	1.3	0.5
		AVERAGE		11.98	8.40	13.59	0.0	5.25	0.11
0404	XA	CONTINUE DESCENT, MIDDLE MARKER TO MAIN GEAR TOUCHDOWN	01:55:14	0.32	23.1	5.8	3.9	2.6	2.6
0404	XB	ROLLOUT FROM TOUCHDOWN TO RUNWAY CLEARANCE	01:55:33	0.80	9.6	6.4	12.0	12.8	8.3
		AVERAGE		1.12	13.45	6.21	9.72	9.93	6.72
		OVERALL AVERAGE		116.35	7.34	9.81	0.90	4.03	0.10

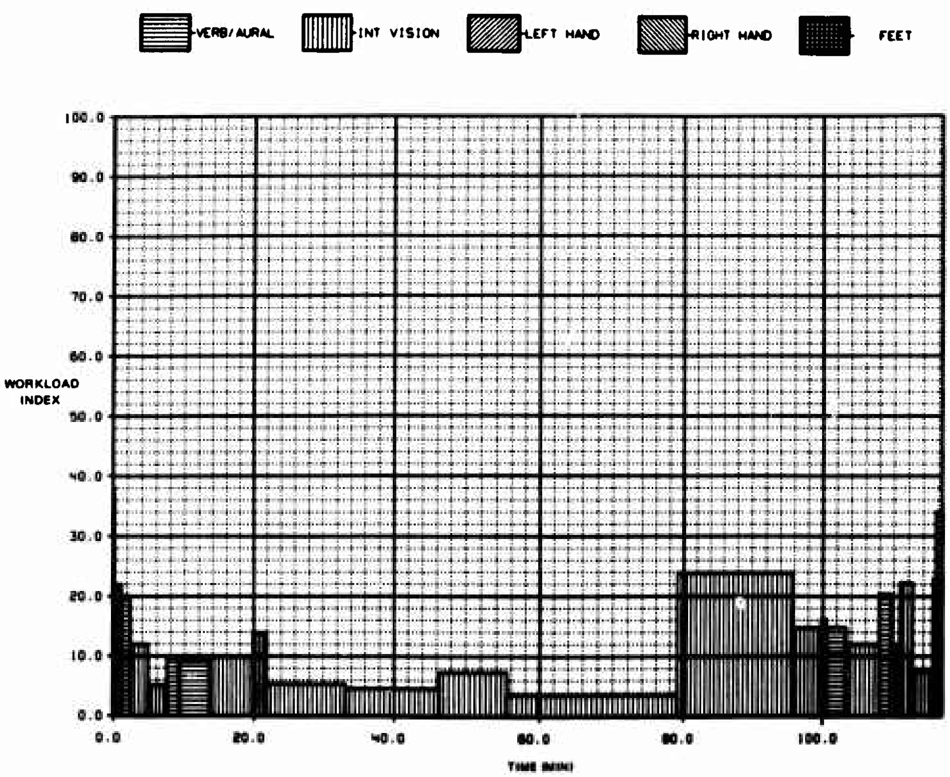


FIGURE 6. PEAK CHANNEL USAGE – CAPTAIN

TABLE 3
EXTERNAL VISION AVAILABILITY ANALYSIS

CREW MEMBER = CAPTAIN

FUNC	MLST	TITLE	STRT TM H M S	DURTN MIN	EVA INDEX IV	EV
00401	XA	ARRIVE AT 10 MINUTE WARNING WPT	00:00:00	5.00	4.87	95.1
00401	XB	INITIATE SLOWDOWN	00:05:00	3.75	31.49	68.5
00401	XC	ARRIVE AT DROP ALTITUDE	00:08:45	1.25	19.35	80.7
00401	XD	ARRIVE AT CARP	00:10:00	0.50	29.07	70.9
00401	XE	ACCELERATE TO 350 KIAS - START DESCENT	00:10:30	1.30	35.72	64.3
00401	XF	LEVEL OFF AT 300 FEET	00:11:48	1.00	19.13	80.9
		AVERAGE		12.80	19.27	80.73
		OVERALL AVERAGE		12.80	19.27	80.73

CREW MEMBER = FIRST OFFICER

FUNC	MLST	TITLE	STRT TM H M S	DURTN MIN	EVA INDEX IV	EV
00401	XA	ARRIVE AT 10 MINUTE WARNING WPT	00:00:00	5.00	11.81	88.2
00401	XB	INITIATE SLOWDOWN	00:05:00	3.75	16.19	83.8
00401	XC	ARRIVE AT DROP ALTITUDE	00:08:45	1.25	24.88	75.1
00401	XD	ARRIVE AT CARP	00:10:00	0.50	36.50	63.5
00401	XE	ACCELERATE TO 350 KIAS - START DESCENT	00:10:30	1.30	28.87	71.1
00401	XF	LEVEL OFF AT 300 FEET	00:11:48	1.00	11.37	88.6
		AVERAGE		12.80	17.03	82.97
		OVERALL AVERAGE		12.80	17.03	82.97

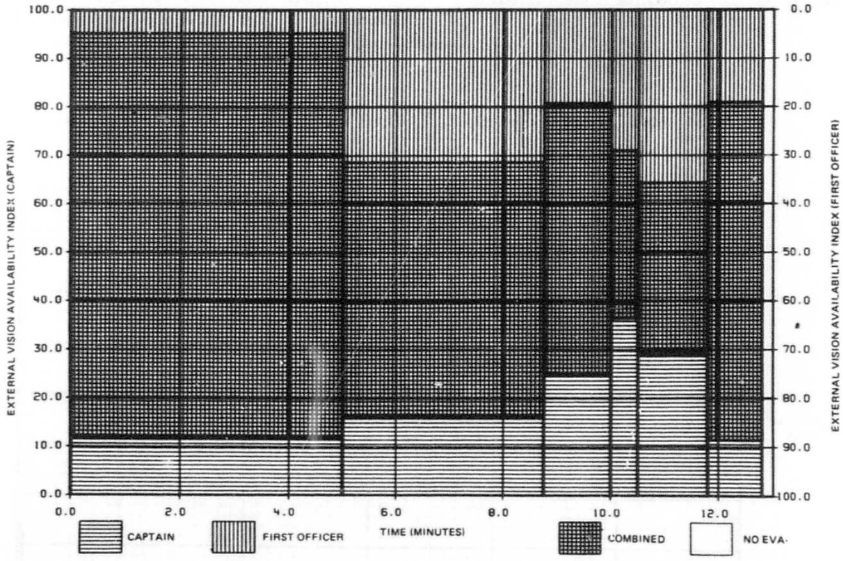


FIGURE 7. COMPOSITE EXTERNAL VISION AVAILABILITY

1 each system;

2 each piece of equipment by part number;

3 controls and displays and

4 the effect of their location based on frequency of use.

In addition, the responsible design groups can be identified.

These measures can be employed to evaluate crew work stations in preliminary design, including the proposed system control and display layouts, operational procedures, and to aid in the certification of new aircraft by validating the design as it applies to the man/machine interface. Additionally, various configurations can be examined in normal operational and in degraded modes where equipment failures have occurred. This latter capability is of great value as it allows analysis of conditions in which the workload may be such as to jeopardize mission accomplishment or safety.

VALIDATION

Because the crew workload index is a function of the ratio of the time required (T_R) to the time available (T_A), there are two aspects to be validated: 1. the segment times which are based on aircraft performance and establish the time available, eg brake release to aircraft rotational velocity (T_A), and 2. the time required (T_R) to perform the tasks within each segment.

The aircraft performance data used to develop the phase and segment times in the flight profile were provided by the Aerodynamics group of Douglas Aircraft, and were validated during engineering test flights. Therefore, they do not require further substantiation. The tasks and task sequences, jointly developed by Human Factors Engineering and Flight Operations, contain all cockpit interface activities considered necessary for effective and safe completion of the flight scenario. These interface activities were verified using a fixed base mockup. Validation of computed task times was therefore needed to ensure that they correspond realistically to actual in-flight times. The methodology for validating the data base task times is described in the following text.

Three flight test programs were conducted to collect data to be used in the validation process. The first set of data was collected during the certification flight of the DC-9-50 in approximately 1977. As part of the validation, a dedicated flight test was conducted that duplicated the scenario used in the MD-80 analytic workload study. This provided timeline data as well as verification of procedures used in the analysis. In addition, during the MD-80 crew complement certification process, a series of test flights was conducted in the high density US Eastern Corridor under airline operating conditions to satisfy Federal Aviation Regulations concerned with the minimum flight crew required for safe aircraft operation. There were nine consecutive days of flying, a total of 55 separate legs with a crew of three two-man teams, each composed of an FAA pilot and a Douglas pilot. Videotapes of flight deck activities recorded during these flights were studied using a micromotion analysis technique to obtain in-flight task time data. Some 122 tasks were examined with relevant human performance times tabulated.

A sample frame of the video tape, shown in Figure 8, indicates the units in which the tasks can be time ie, hours, minutes seconds, and tenths of a second. This is accomplished with a digital time generator which superimposes these data directly on the video tape (eg, 3 hours, 25 minutes 36.3 seconds). On the actual tape, the resolution is sufficient to distinguish individual controls and displays, allowing for precise determination of physical motion times.

Table 4 presents an example of three tasks and their comparative crew workload data base and in-flight measured times. In all, 122 tasks were examined in this manner. The results are shown in Figure 9 illustrating the linear regression line of the 122 points. An excellent correlation was obtained with a coefficient equal to 0.81.

As a result it was concluded that the task/timeline analysis procedure provides a reasonably accurate index for predicting the time required to complete observable tasks within the constraints of an actual mission. The detailed methodology and results of the data base validation process are presented in a previous report (8).

APPLICATIONS

Aircraft Comparison During Early Design

The comparative analysis capabilities of the program enable the new design to be compared to an existing aircraft that is known to have an acceptable workload profile and is duly certified. The existing aircraft will be referred to as the MD-X. The

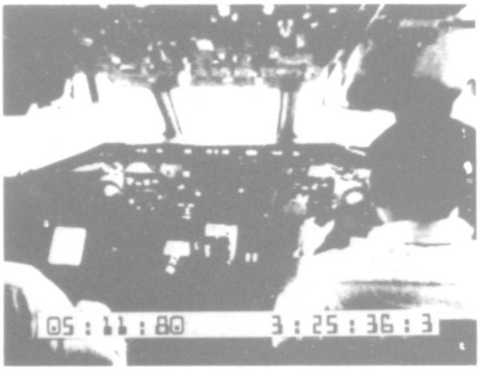


FIGURE 8. SAMPLE FRAME FROM VIDEOTAPE – IN-FLIGHT RECORDING

TABLE 4
IN-FLIGHT AND DATA BASE
TASK COMPARISON

IN-FLIGHT	TIME (SEC)		DATA BASE	TIME (SEC)
			ADJUST HEADING KNOB, PUSH ILS BUTTON	
CAPTAIN MOVES HAND TO HDG SEL KNOB FROM REST, ADJUSTS KNOB, MOVES HAND TO ILS BUTTON – PUSHES – RETURNS HAND TO REST		a.	CAPTAIN REACHES TO HDG SEL KNOB	0.63
		b.	ROTATES TO SET HEADING IN WINDOW	3.83
		c.	MOVES HAND TO ILS BUTTON	0.35
		d.	PUSHES BUTTON	0.57
		e.	VERIFIES BUTTON ILLUMINATES	0.20
		f.	RETURNS HAND TO REST	0.49
	6.4			6.07
			SET RADIO ALTIMETER	
FIRST OFFICER SETS NO. 2 RADIO ALTIMETER WITH RIGHT HAND (REACHES AND RETURNS TO REST)		a.	FIRST OFFICER MOVES HAND FROM REST TO NO. 2 RADIO ALTIMETER KNOB	0.84
		b.	ROTATES TO SET BAROMETER	1.30
		c.	RETURNS HAND TO REST	0.44
	2.6			2.58
			SET ILS FREQUENCY – NAV 1 AND 2	
TIMED FROM FIRST OFFICER'S HAND ON NAV 2 – SETS FREQ, REACHES TO NAV 1 FREQ KNOB, ROTATES TO SET, RETURNS HAND TO REST		a.	FIRST OFFICER SETS NAV 2 IN WINDOW	3.29
		b.	MOVES HAND TO NAV 1 FREQ KNOB	0.66
		c.	ROTATES TO SET FREQ IN WINDOW	3.29
		d.	RETURNS HAND TO REST	0.72
	6.5			7.29

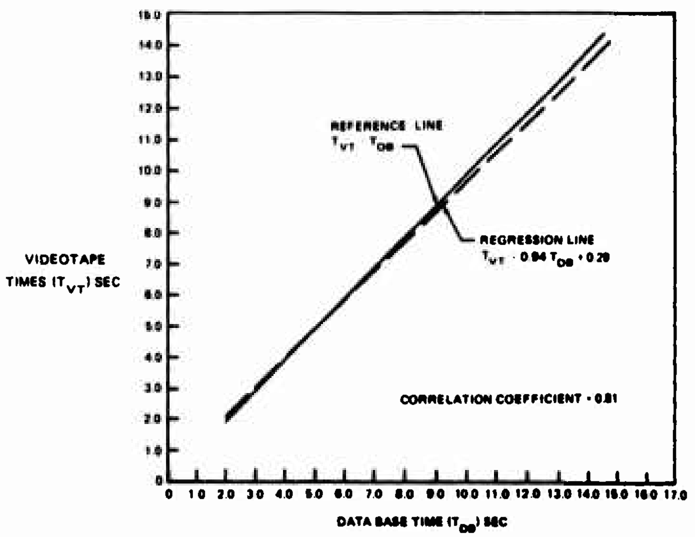


FIGURE 9. TASK TIME VALIDATION – VIDEOTAPE VERSUS DATA BASE TIMES (122 TASKS)

configuration incorporates a digital flight guidance system and autothrottle/autopilot capabilities. It also features conventional instrumentation displays. The new aircraft, designated the MD-XX, is equipped with a flight management system integrated with an automatic flight control system. Four electronic (CRT) instrument displays feature redundant primary flight and navigation displays, while two multifunction displays incorporate such features as phase-of-flight display, caution/warning alerts, fault/limit lists, and procedure/checklists.

In this example, the two aircraft are compared using a flight scenario involving the critical phases of descent, approach, and landing at LaGuardia airport in New York. The results of this analysis are shown in Figure 10 which illustrates the workloads of the Captain and First Officer. It is significant to note that while the operational systems of the advanced flight deck are sophisticated, there appears to be only a slight difference in workload compared to the baseline aircraft. While the First

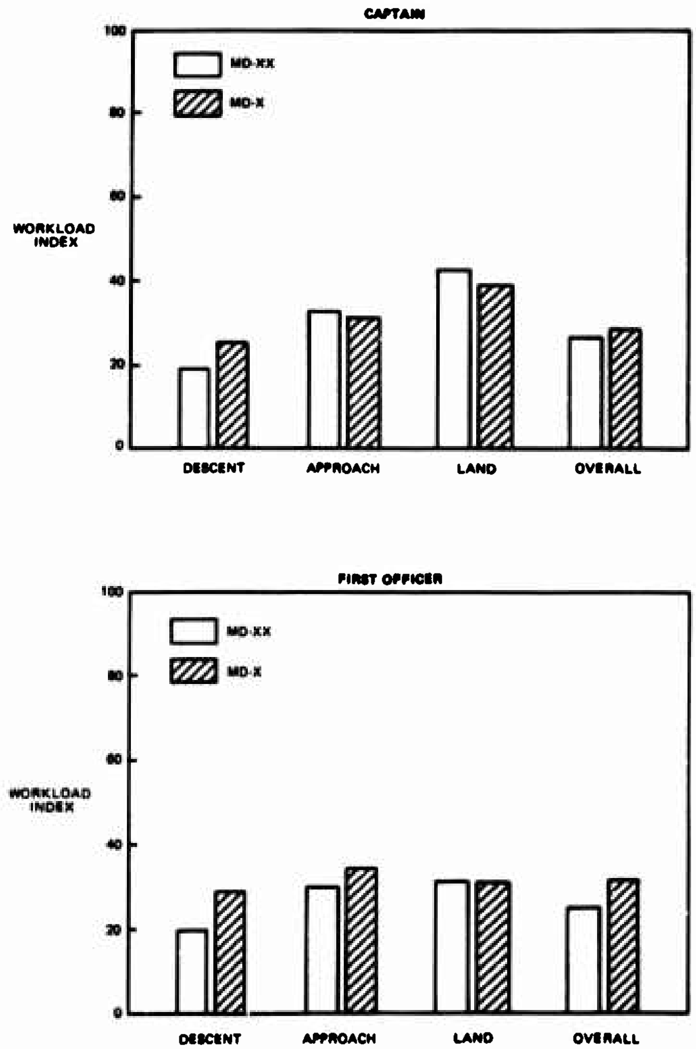


FIGURE 10. FLIGHT CREW WORKLOAD – DESCENT TO TOUCHDOWN

Officer's workload for the MD-XX is shown to be equal to or lower than on the MD-X, there appears to be some slight increase for the Captain. Further analysis indicated that the cause of this slight increase was as follows:

1 The MD-XX has an additional task, requiring the navigation display scales to be reset as the aircraft get close to touchdown.

2 During level-off, the altimeter in the MD-XX requires a slightly longer time to read and the flight data systems control display unit must be observed to cross-check the flight and navigation displays.

This analysis illustrates the manner in which the flight crew workload program can be effectively utilized. In this study, it was determined that the advanced configuration flight deck had slightly higher workloads during approach and landing that a conventional cockpit for the Captain's duties and an acceptable workload for the First Officer. The specific causes of the workload differential were subsequently established, allowing for redesign of equipment or a change in operational procedures to decrease the workload to acceptable levels.

The analysis does not stop at this point, however, but goes into more detail examining detailed flight segments and time breakdowns to ensure that, while average workloads are acceptable, there are no sharp peaks that are lost in the averaging. In addition, further study involves the imposition of contingency modes on the flight scenario to evaluate the workloads under these conditions.

Contingency Analysis

A contingency analysis is expressly designed to evaluate the impact of a degraded mode of operation on flight crew workload. This is accomplished by imposing an abnormal or emergency condition in each flight scenario used for the normal crew workload analysis and determining relative differences or changes.

For example, consider the situation in which one member of a two-member crew becomes incapacitated while in flight. Four steps must be taken to enable a safe landing:

1 maintain control of the aircraft;

2 take care of the incapacitated crew member

3 reorganize the flight deck; and

4 land the aircraft.

In this example, the First Officer becomes incapacitated during descent. The Captain's basic tasks remain unchanged, and he assumes as many of the First Officer's duties as is practical. The number of traffic advisories and communications with the Air Traffic Controllers (ATC) is the same as in the normal scenario. Additional verbal/aural tasks are inserted for communications with the ATC and company personnel to present the incapacitation as realistically as possible. Only those First Officer's tasks considered necessary for safety of flight are assumed by the Captain.

Two types of comparison are performed:

1 a new aircraft configuration with normal operating conditions versus a new aircraft configuration with degraded mode conditions; and

2 a new aircraft with degraded mode operating conditions versus a baseline aircraft with degraded mode conditions.

Examples of results by flight phase are shown in Figure 11. The new aircraft, the MD-XX, while having an increased workload for the Captain when his First Officer is incapacitated, does not overload the Captain. In the second comparison, when the new aircraft is compared to the baseline aircraft, the MD-X in the incapacitated crew member mode, a significantly lower workload is imposed on the Captain.

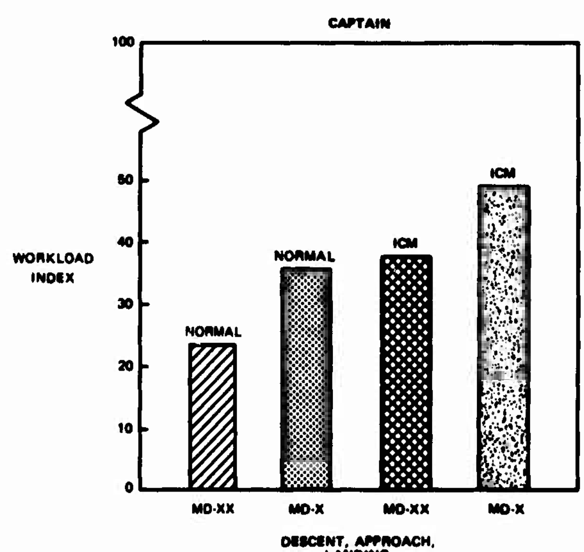


FIGURE 11. INCAPACITATED CREW MEMBER (ICM) WORKLOAD ANALYSIS

In addition, Figure 12 presents examples of the effect of other contingencies on average workloads during the flight. This indicates the versatility of the workload program and the variety of contingency situations which can be analyzed.

Subsystem or Equipment Analysis

Workload analysis may also be used as a design tool in the selection of a control and display layout for a particular subsystem. Figure 13 shows two proposed audio panel configurations for a modern jet transport. Audio Panel 1 represented the conventional panel with an on-off lever, and a separate control or volume adjustment.

In the second configuration, single continuous adjustment knobs incorporating push-on/push-off features are used for volume control. This pushbutton feature permits presetting the knobs to normal or to anticipated monitoring volume levels independent of the on-off function, a capability not available on Audio Panel 1. The time devoted to making volume adjustments may therefore be less with Audio Panel 2 than with Audio Panel 1.

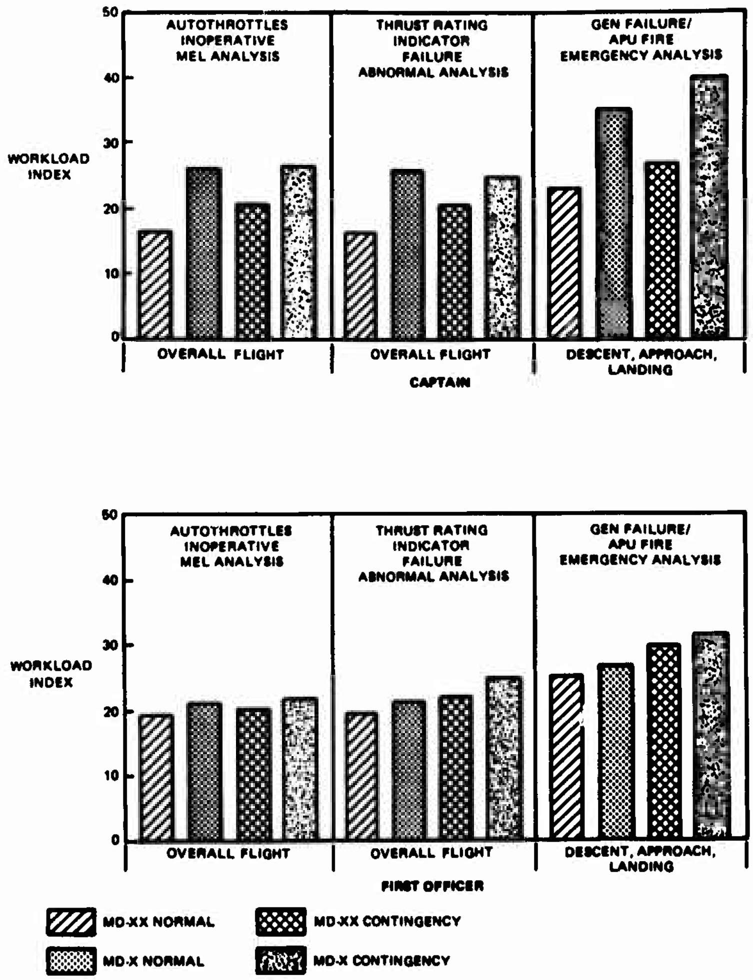


FIGURE 12. CONTINGENCY WORKLOAD ANALYSIS

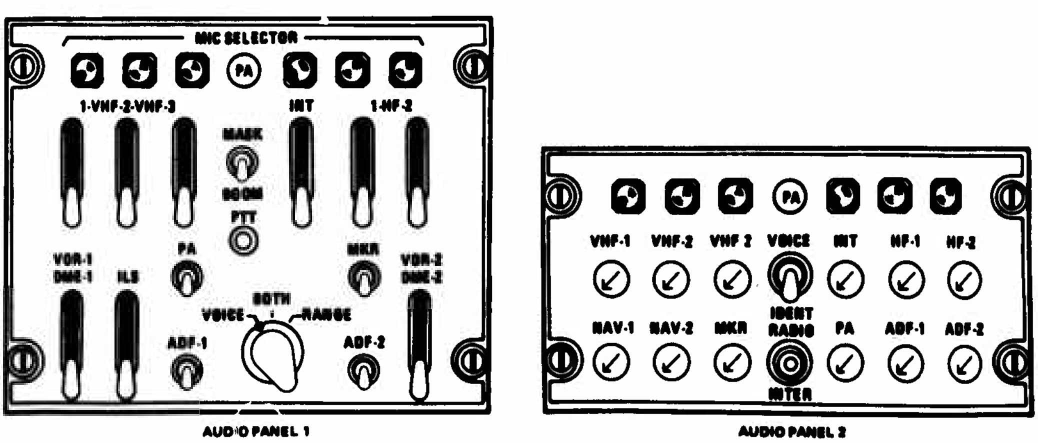


FIGURE 13. AUDIO PANEL WORKLOAD EVALUATION

TABLE 5
WORKLOAD RESULTS–
AUDIO PANEL EVALUATION

FLIGHT SEGMENT		WORKLOAD INDEX	
		CAPTAIN	FIRST OFFICER
TAKEOFF	AP1	1.98	5.69
	AP2	1.98	5.75
	Δ%	0.00	0.99
CLIMB	AP1	4.49	11.82
	AP2	4.49	10.71
	Δ%	0.00	−9.35
CRUISE	AP1	2.42	5.35
	AP2	2.35	4.67
	Δ%	−2.91	−12.68
DESCENT	AP1	13.24	27.31
	AP2	13.24	24.53
	Δ%	0.00	−10.11
APPROACH	AP1	5.29	9.71
	AP2	5.29	9.77
	Δ%	0.00	0.66
LANDING	AP1	0.00	0.00
	AP2	0.00	0.00
	Δ%	0.00	0.00
OVERALL	AP1	3.69	8.12
	AP2	3.65	7.38
	Δ%	−1.19	−9.06

This supposition is confirmed by examination of the numerical results of the workload evaluation presented in Table 5. In this case, Audio Panel 1 is considered the "standard" configuration and the results show reductions in the overall communications workload for the new system of approximately 1 percent for the Captain and 9 percent for the First Officer. Naturally, large workload reductions would be expected for the First Officer because one of his primary tasks is communications.

Another significant item extracted from this analysis is that workload reductions for the First Officer occur primarily during the climb and descent segments, which normally represent high workload phases of flight. Thus, any reduction in workload during these periods is especially beneficial. If the reductions occurred only during the low-workload cruise period and were of the low level shown for the Captain in Table 5, then the new development effort might be questioned.

Consequently, this comparative workload analysis of alternative audio control panel designs supports two conclusions:

1 the design for Configuration 2 shows superior workload characteristics over that of Configuration 1 and therefore is worthy of further development; and

2 in-flight communications workloads for future aircraft may be reduced by employing volume control designs which incorporate and on-off feature that acts independently of the volume level adjustment.

Certification Analysis

The flight crew workload analysis and design system can also be applied to aid in demonstrating compliance with Federal Aviation Regulations (FAR 25.1523) and its Appendix D (Minimum Flight Crew) (9). In this case, a comparative analysis is made between the new aircraft to be certified and an aircraft that has been operating in an airline environment for a number of years, is considered to have an acceptable level of workload, and has the crew complement certified under applicable Federal Aviation Regulations.

A study of this type is conducted to demonstrate how design differences in the crew station layouts, controls, and displays of the two aircraft affect flight crew workload during normal and degraded flight modes. The results for the normal workload are plotted in Figure 14. Overall reductions in workload are shown for the Captain and First Officer of the new aircraft equal to 32 and 7 percent, respectively. As indicated in Figure 14, there is a significant reduction in the captain's workload on the new aircraft in all flight phases, ranging from 26.8 percent during cruise to 44.6 percent during climb.

Additional analysis would be presented to the regulatory agency demonstrating the effect of abnormal and emergency flight situations on crew workload. An analysis of this type was submitted to the Federal Aviation Administration during the recent certification of the MD-80 aircraft.

Additional Analytic Capability

The task/timeline workload analysis methodology can also be applied as follows to all areas of aircraft development from the earliest concept through development, detailed design, certification, and crew training.

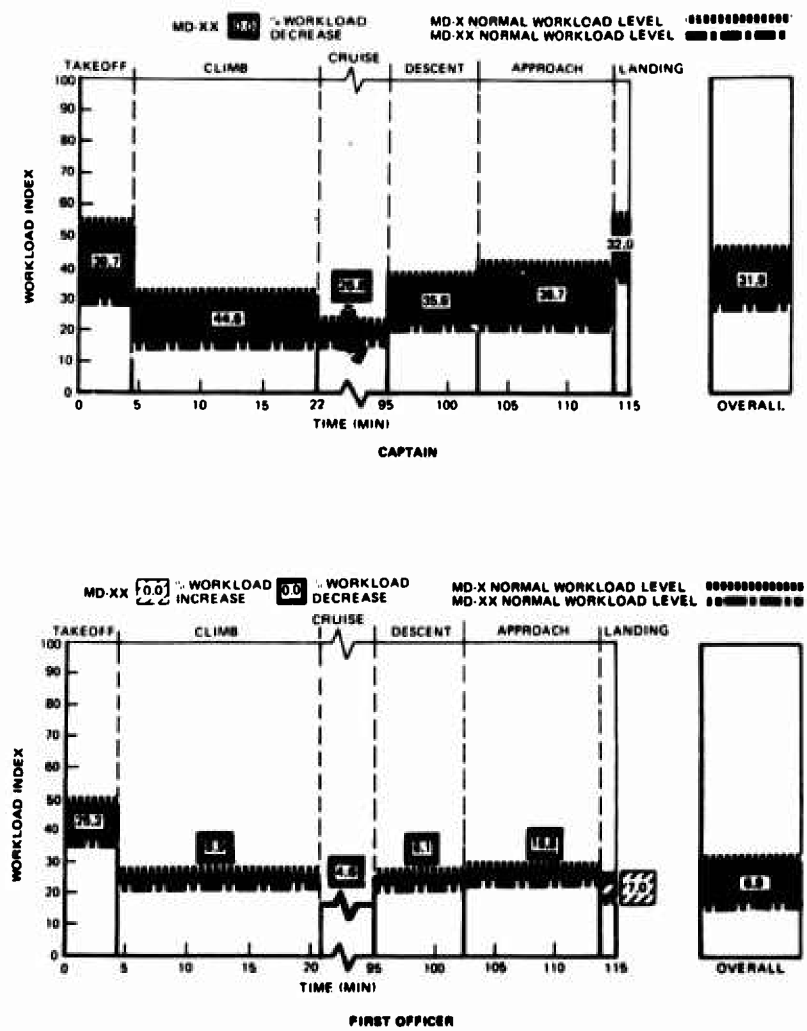


FIGURE 14. FLIGHT CREW WORKLOAD COMPARISON

1 Advanced design — As a tool in the creative stage of aircraft design to systematically determine such matters as allocation of functions to either a crew member or automation, and determination of the crew complement.

2 Design/development — For assistance in equipment placement, display format development, crew duty allocations, and operational procedures. During the design/development stage, the workload program may be used to design alternative design concepts in various trade studies involving different systems or subsystems.

3 Detailed design — The workload analysis process continues to verify crew duty allocation, the effects of contingencies on crew workload and mission completion success (or abort). Verification of the data base in the simulator mockup phase of development is also initiated. During this stage, when the design is frozen, the instructional development and training program is initiated, and the task listings, developed for the workload study, become useful in preparing training materials and flight manuals.

DISCUSSION

While there have been many symposia, papers and discussion groups devoted to the subject of workload, there seems to be no commonly accepted definition of the term. Because of this, there have been many different approaches to the qualitative and quantitative measurement of workload. The approach taken in this paper is concerned not so much with obtaining an absolute measure of workload — which would be highly desirable but is currently beyond our understanding — but with being able to use the comparative concept of workload measurement as a tool to aid in the design of work stations.

The task/timeline approach to workload quantification has certain limitations which preclude its being used in the true sense of a metric. In particular:

1 It does not consider cognitive or mental activities.

2 It does not take into account variations associated with ability and experience or dynamic, adaptive behaviour.

3 It cannot deal with simultaneous or continuous-tracking tasks.

At present, sufficient data do not exist on variations in task time associated with differences in operator capability or learning ability to include this factor in the analysis. Tasks are considered as being performed by an average operator.

With regard to simultaneous tasks, the workload program considers a serial approach to task performance and thus the results on this basis might be considered somewhat conservative. Continuous-tracking tasks are handled by an assumption of serial task performance. For aircraft control wheel or throttle continuous-input tasks, flight test data were examined to determine pilot discrete inputs to these controls. Averages from these data on frequency and duration may then be used in the analysis.

Admittedly, all of these compromises do not allow for the expression of an absolute metric of workload. In fact, there is no universal agreement in the industry as to what levels, derived, from task/timeline analysis, are considered acceptable — whether the level be overload or underload.

No accepted method has been developed to adequately compensate for these limitations. Subjective assessment or simulator studies are sometimes used to help improve insights into the significant of these factors. In general, we support this approach to improving the understanding of human ability in system operation. Each approach has its value. To use one is not to deny the value of the other.

The task/timeline approach to workload analysis which is described in this paper, however, was subject to close scrutiny by many agencies because of the controversy over a two-member flight crew. The following comment from a presidential task force is considered significant (10).

"At present, the only generally accepted method for evaluating workload is task/timeline analysis based on comparison with previous aircraft designs. This technique, supplemented by improved subjective evaluation methods applied by qualified pilots, will offer the best means for demonstrating compliance with FAA crew complement criteria."

The comparative concept provides a basis for extensive use of this methodology and, in fact, allows for a wide range of evaluation of variations in work station design. Comparisons can be made between difference aircraft, systems, or individual pieces of equipment, or even to examine the effectiveness of different panel locations for controls or displays.

If the baseline used in the comparison is considered to have an acceptable workload, then the analysis will indicate which has the lowest workload and by what magnitude. Even when used in a noncomparative mode, the technique allows for the assessment of those portions of scenario where workload levels can be expected to be substantially higher than the average, and thus allows for more detailed analysis aimed at minimizing peak workloads. Another plus is the fact that the procedure can be applied early in the design cycle and thus have the ability to influence design. Though mockups and simulators would be advantageous in establishing crew procedures, they are not absolutely required in the analytical process.

A typical workload analysis on a new aircraft or work station is considerably labor-intensive in that extensive task listings describing detailed operation of the system under consideration must be prepared. Moreover, a number of different scenarios or missions may have to be considered. Once the baseline is developed, however, it can then be modified to reflect various concepts or design options with little difficulty. It is fairly evident, however, that the only way to accomplish an analysis of this magnitude is with an automated facility. Machine computational capabilities plus the flexibility of the technique allows for extensive graphic presentation and facilitates analysis.

An effort is currently underway to improve the computer program and its input software. The new program will automatically generate various scenarios by supplying formatted flight segments with their associated time factors, and provide simplified input formats for task generation. It will contain an extensive library of system procedures with will allow for rapid computation of task time. In addition, consideration is being given to adapting methodology developed for the assessment of human reliability for the program, thus providing an additional measure of human performance to supplement the workload analysis.

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